

SYSTEM AND METHOD FOR DELIVERING HIGH-PERFORMANCE ONLINE MULTIMEDIA SERVICES

Inventor: Milo S. Medin

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation of prior U.S. Patent Application No. 09/427,778, entitled METHOD AND SYSTEM FOR RESTRICTING ACCESS TO USER RESOURCES, filed on October 26, 1999 by Ralph W. Brown, Robert Keller, Milo S. Medin and David Temkin, which is a continuation-in-part of prior U.S. Patent Application No. 08/811,586, now U.S. Patent No. 6,370,571, entitled SYSTEM AND METHOD FOR DELIVERING HIGH-PERFORMANCE ONLINE MULTIMEDIA SERVICES, filed on March 5, 1997, by Milo S. Medin, and is related to U.S. Patent Application No. 09/428,235, entitled METHOD AND SYSTEM FOR AUTHENTICATING AND AUTHORIZING USERS, filed on October 26, 1999 by Ralph W. Brown, Robert Keller, and Milo S. Medin, each of which is hereby incorporated by reference herein.

TECHNICAL FIELD

[0002] This invention relates to the high-performance end-to-end delivery of online multimedia services, including Internet services such as World Wide Web (WWW) access. The invention combines a scalable, hierarchical, distributed network architecture and processes for replicating, caching, and multicasting.

DESCRIPTION OF RELATED ART

[0003] Cable modems enable an end-user to make a high-bandwidth connection to a network system. For example, using a digital modulation technique called quadrature phase-shift keying (QPSK), a downstream connection with a bandwidth of about 10

megabits per second may be made by occupying a single 6 MHz channel out of the 750 MHz total coaxial capacity typical in most modern cable television systems, and an upstream connection with 768 kilobits per second may be made by occupying 600 KHz of that capacity. The bandwidth may be increased or decreased by occupying more or less bandwidth as desired. Other modulation techniques are also available, such as quadrature-carrier amplitude modulation (QAM). The technology for such connections is available, for example, from companies such as Motorola, the LanCity division of Bay Networks, and Hewlett Packard. Unlike telecommunications connections that use dedicated switched lines, cable modem connections use a shared medium and so can be continuously "on" without substantial waste of resources.

[0004] Although cable modems provide a practical high-speed connection from the end-user to the network, nevertheless, such a high-speed connection is not enough by itself to deliver high-performance online services, especially with regards to Internet services, such as World Wide Web (WWW) access. In order to deliver high-performance end-to-end Internet service, solutions are needed to the problems of redundant data traffic, unreliable network performance, and scalability.

[0005] The Internet is a publicly accessible internetwork of networks. Internet Service Providers (ISPs) provide Internet access to businesses and consumers via points of presence (POPs) that are connected to network access points (NAPs) which are entry points to the Internet.

[0006] One of the Internet's architectural weaknesses, and the cause of many of its current performance issues, is its highly redundant data traffic. For example, when an end-user downloads a video clip from the popular CNN (Cable News Network) Web site, data packets containing bits of the video clip are "pulled" all the way across the Internet: from the CNN WWW server, to CNN's ISP (ISP), through potentially several paths across the Internet including multiple interchanges on the Internet backbone, to the end-

user's ISP, and finally to the end-user's computer system. If the end-user's next-door neighbor soon thereafter requests the very same video clip from the CNN Web site, she also pulls the bits of the clip all the way across the Internet. The result is that many of the same bits are moved over and over again over the same communication paths going to CNN's ISP, across the Internet, and to the end-user's ISP.

[0007] Another weakness of the Internet is its unreliable performance. The Internet performs in an intermittent or otherwise unreliable manner due in part to traffic bottlenecks which constrict the flow of data in the system. Unfortunately, there is no coherent scheme to deal with such bottlenecks because of the decentralized nature of the management of the Internet.

[0008] Yet another weakness of the Internet is its lack of security. This lack of security is particularly significant because it tends to inhibit electronic transactions and is in part due to the public nature of the Internet.

[0009] In order to provide for future growth for a network, it is important that the network architecture and operation be scalable to larger size and/or higher speeds. If the architecture is not readily scalable to a larger size, network performance will suffer when the network is expanded. If the network is not readily scalable to higher speeds, performance will suffer when network traffic increases.

SUMMARY OF THE INVENTION

[0010] The present invention relates to a system and method for delivering high-performance online multimedia services, including Internet services such as WWW access, that satisfies the above-described needs. The system and method combine a scalable, hierarchical, distributed network architecture and processes for replicating and caching frequently-accessed multimedia content within the network, and multicasting content customized per region or locality.

[0011] The digital network architecture couples a high-speed backbone to multiple network access points (NAPs) of the Internet, to a network operation center, to a back office system, and to multiple regional data centers. Each regional data center couples to several modified head-ends, which in turn couple via fiber optics to many neighborhood optoelectronic nodes. Finally, each node couples via coaxial cable and cable modems to multiple end-user systems. The architecture separates the public Internet from a private network with enhanced security to facilitate electronic transactions.

[0012] The backbone provides a transport mechanism that can be readily scaled to higher speeds. The backbone also enables bandwidth to the Internet to be increased, without reconfiguring the network structure, either by increasing the speed of the existing couplings at the NAPs or by adding a new coupling to a NAP. Finally, the backbone allows service to be extended to a new area, again without reconfiguring the network structure, by simply coupling a new regional data center (RDC) to the backbone.

[0013] The network operation center (NOC) is a centralized control center which efficiently coordinates the management of the privately controlled network. The network management system (NMS) server at the NOC coordinates NMS clients at the RDCs. The management of the private network enables the optimization of performance. The hierarchical nature of the management allows consistent system configuration and management which results in a high level of overall network security and reliability.

[0014] Certain frequently-accessed information or content is cached within and replicated amongst the RDCs. This reduces traffic redundancy since an end-user's request for data that has been so replicated or cached may be fulfilled by the "nearest" (most closely coupled) RDC. In addition, the RDCs are able to multicast content that has been customized for the region to end-users in the region. This further reduces redundant traffic. Finally, the RDCs contain NMS clients that monitor and proactively manage

network performance in the region so that traffic bottlenecks may be identified and overcome. The NMS detects and figures out the locations of the faults throughout the network, correlates failures, and can report faults to the appropriate repair entities, create trouble tickets, and dispatch repair crews.

[0015] Frequently-accessed content is also cached within the modified head-ends. This further reduces redundant traffic because an end-user's request for content that has been so cached may be fulfilled by the "nearest" modified head-end.

[0016] Finally, the hierarchical nature of the private network architecture enables multicast data to be efficiently customized for each region receiving the multicast.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] Figure 1 is a diagram of a scalable, hierarchical, distributed network architecture for delivering high-performance online multimedia services constructed according to a preferred embodiment of the present invention.

[0018] Figure 2 is a diagram of a private backbone and connecting routers in a preferred embodiment of the present invention.

[0019] Figure 3 is a diagram of a regional data center in a preferred embodiment of the present invention.

[0020] Figure 4 is a diagram of a modified head-end in a preferred embodiment of the present invention.

[0021] Figure 5 is a diagram of a regional computer within a regional data center in a preferred embodiment of the present invention.

[0022] Figure 6 is a diagram of a caching computer within the modified head-end in a preferred embodiment of the present invention.

[0023] Figure 7 is a diagram of a network operations center in a preferred embodiment of the present invention.

[0024] Figure 8 is a diagram of a central computer within a network operations center in a preferred embodiment of the present invention.

[0025] Figure 9 is a diagram of a back office system in a preferred embodiment of the present invention.

[0026] Figure 10 is a diagram of a back office computer within a back office system in a preferred embodiment of the present invention.

[0027] Figure 11 is a flow diagram of a preferred method for providing data requested by a user to their system 124.

[0028] Figure 12 is a flow diagram of a preferred method of replicating data from a content provider.

[0029] Figure 13 is a flow diagram of a preferred method of multicasting content that is customized to region or locality.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0030] The preferred embodiments of the present invention are now described with reference to the figures.

[0031] Figure 1 is a diagram of a scalable, hierarchical, distributed network architecture for delivering high-performance online multimedia services constructed according to a preferred embodiment of this invention. In the architecture of the present invention, the distributed public Internet (top portion) 170 is separated from a hierarchical private network (bottom portion) 180 under private control.

[0032] A high-speed, private backbone 102 is connected via routers (R) 104 to network access points (NAPs) 106 of the Internet. In a preferred embodiment of the present invention, the private backbone 102 runs asynchronous transfer mode (ATM) service over bandwidth leased from commercial providers such as MCI Communications, AT&T, or Sprint. ATM is a high-speed, cell-based service which allows different types of traffic to be supported at different levels of service. The routers 104 are internet protocol (IP) routers such as those commercially developed by Cisco Systems.

[0033] The NAPs 106 are access points into the Internet to which a number of routers can be connected. NAPs 106 are located, for example, in San Francisco, Chicago, and Washington, D.C. A typical NAP 106 is a fiber distributed data interface (FDDI) ring which connects to one or more tier 1 (national) backbones 108 of the Internet, such as the commercially operated backbones of Advanced Network & Services (ANS), MCI Communications, or Sprint. FDDI is a high-speed Token Ring network designed specifically to use optical fibers as connecting media.

[0034] Each of these tier 1 backbones 108 connects to one or more tier 2 (regional) networks 110, which in turn connects to one or more tier 3 (local) networks 112. Finally, each tier 3 network 112 connects to one or more local area networks (LANs) 114. A LAN 114 may include various servers, such as, for example, the World

Wide Web server which provides the popular ESPN SportZone web site for sports information. There may also be private peering between networks in the same tier. For example, a tier 1 network 108 may have a connection to another tier 1 network.

[0035] Note that in Figure 1 the networks above the NAPs 106 (i.e. the tier 1 backbones 108, the tier 2 networks 110, the tier 3 networks 112, and the LANs 114) are part of the publicly accessible Internet 170. Thus, for example, information made available on their WWW servers (http servers) may be accessed by client computer systems (http clients) connected to the Internet. Of course, Figure 1 shows only a simplification of the complexity of the Internet 170. For example, a tier 1 network 108 may connect to various dial-up providers to which end-users may connect via modems.

[0036] The private backbone 102 is also connected via routers 116 to one or more regional servers 302 (see Fig. 3) at regional data centers (RDCs) 118. Each of the RDCs 118 is connected to one or more local servers 402 (see Fig. 4) at modified head-ends 120 within a hybrid fiber-coax (HFC) distribution system. Each of the local servers 402 at the modified head-ends 120 is connected (via fiber optics) to many neighborhood optoelectronic (O/E) nodes 122 within the HFC distribution system. There are typically over a hundred nodes 122 connected to each modified head-end 120, even though Fig. 1 shows only a few for convenience and ease of understanding. Finally, the nodes 122 are connected (via coaxial cable and cable modems) to many end-user systems 124 located typically within people's homes or offices. There are typically over a hundred end-user systems 124 connected to each node 122, even though Fig. 1 shows only a few for convenience and ease of understanding.

[0037] In addition, at least one of the routers 116 connects private backbone 102 to a network operations center (NOC) 126 and a back office system (BOS) 128. The NOC 126 is the centralized control center which efficiently coordinates the management of the private network 180. The BOS 128 includes software for subscriber management

and billing. The NOC 126 and the BOS 128 are also connected together so that they can communicate with each other without going through the router 116.

[0038] Furthermore, the private backbone 102 connects via an additional router 130 to a particular LAN 114 in order to give the network 180 more direct access to content on that particular LAN 114. The particular LAN 114, for example, may be one which houses a server for a frequently accessed commercial WWW site such as the ESPN SportsZone site. In such a case, data from that LAN 114 may travel towards an end-user 124 either via the Internet 170 (for example, on a path through tier 3 112, tier 2, 110, tier 1 108, NAP 106, and router 104) or via the short-cut through the additional router 130 which bypasses the Internet 170.

[0039] Finally, the private backbone 102 may peer with another private network, such as a tier 1 network 108. This private peering is implemented via a connection between the two networks. Peering generally involves a coupling between two networks on the same hierarchical level.

[0040] Note that in Figure 1 the networked objects below the NAPs 106 (i.e. the private backbone 102, the routers 104, 116, and 130, the RDCs 118, the modified head-ends 120, the nodes 122, the end-user systems 124, the NOC 126, and the BOS 128) are part of a private network 180 under private control.

[0041] Figure 2 is a diagram of the private backbone 102 and connecting routers 104 116, and 130 in a preferred embodiment of this invention. In this embodiment, the private backbone 102 is based on an interconnected network of switches 202 capable of supporting Asynchronous Transfer Mode (ATM) service.

[0042] The ATM service is a high-speed, cell-based, switching technique which provides bandwidth on-demand. This capability of the ATM service to provide bandwidth on-demand allows each type of traffic to be supported at an appropriate level

of service, and thus makes possible the integration of voice, video, and data traffic into one network. The physical layer under the ATM service (i.e. the connections between the ATM switches 202) is typically provided by Synchronous Optical Network/Synchronous Digital Hierarchy (SONET/SDH) technology. Widely supported speeds of SONET/SDH currently include 155 Mbps, 622 Mbps, and 2.488 Gbps.

[0043] The switches 202 connect via routers 104 to the NAPs 106. Routers 104 are currently comprised of a commercially available Internet Protocol (IP) router and an interface board to interface between the ATM service and the IP layer. For example, the IP router may be Cisco Systems' model 7505 router, and the interface board may be an "AIP" board that connects to the IP router. In effect, the AIP board couples the backbone 102 to the IP router. Such a configuration is available from Cisco Systems, San Jose, California.

[0044] The switches 202 also connect via routers 116 to the high-availability (H/A) regional servers 302 (see Fig. 3) at the RDCs 118. These routers 116 also comprise an Internet Protocol (IP) router, such as the Cisco 7505 router, and an interface board, such as the AIP board. In addition to connecting to the RDCs 118, at least one of these routers 116 also connects to the NOC 126 and the BOS 128 in order to provide a communications channel for network management.

[0045] Finally, the switches 202 may connect via routers 130 directly to particular LANs 114 in order to give end-user systems 124 more direct access to content on those particular LANs 114. These routers 130 comprise an IP router, such as Cisco System's 7200 router, and an interface board, such as the AIP board.

[0046] Figure 3 is a diagram of a regional data center (RDC) 118 in a preferred embodiment of this invention. The RDC 118 includes a H/A regional server 302, a terminal server 308, a high-speed switch 310, and various blocks 304.

[0047] The regional server 302 may include a cluster of computers for high availability and performance. In this embodiment, the regional server 302 comprises two regional computers 304 which are both able to access a regional disk array 306 via a regional array controller 305. The regional computers 304 may be, for example, based on servers commercially available from Sun Microsystems, and the high-speed connections may be, for example, connections based on the Fiber Channel Standard. The regional computers 304 and the regional disk array 306 may be configured such that they provide high availability to one of the various RAID levels. In RAID (Redundant Array of Independent Disks) Level 1, redundancy is provided by mirroring data from one drive to another. In RAID Level 5, data is stored across multiple drives, parity is generated, and parity is distributed across the drives in the array 306. RAID Levels are well known in the computer industry.

[0048] The two regional computers 304 each have a connection 320 to the terminal server (TS) 308. The terminal server 308 connects via a modem to the public switched telephone network (PSTN) to provide an alternative backup communication and control channel between the RDC 118 and the NOC 126. A terminal server is generally a computer capable of either input or output to a communication channel. Here, the terminal server 308 is capable of both receiving input from and sending output to the PSTN.

[0049] The regional computers 304 also each have a connection 322 to the high-speed switch 310. These connections 322 may be made, for example, using 100 BaseT Ethernet (which is well known in the industry and can transfer data at 100 Mbps), and the high-speed switch 310 may be capable of switching data at gigabit per second speed.

[0050] The high-speed switch 310 has a connection via one of the routers 116 to one of the ATM switches 202 of the private backbone 102. The high-speed switch 310 also has one or more connections via blocks 314 to modified head-ends 120 or to a

regional network 119 (which in turn connects to several modified head-ends 120). Each block 314 may comprise either an ATM switch, a router, or a point-to-point connection, as appropriate, depending on the system to which the high-speed switch 310 is connecting. The blocks 314 may also have connections to the terminal server 308 as shown by line 324.

[0051] Figure 4 is a diagram of a modified head-end 120 in a preferred embodiment of this invention. The modified head-end 120 includes a caching server 402, a switch 404, many head-end modems 406 and multiplexers 407, a router 408, a terminal server (TS) 410, a monitor device 412, and analog head-end equipment 414.

[0052] In this embodiment, the caching server 402 comprises two interconnected caching computers 403 which may be, for example, based on computers commercially available from Silicon Graphics Inc. of Mountain View, California. Two caching computers 403 are used to provide more efficient and robust caching service. For example, the cache may be partitioned between the two computers 403 by having data with URLs of an odd number of characters being cached at one computer 403 and data with URLs of an even number of characters being cached at the other computer 403. Moreover, if one computer 403 goes down, then requests may be sent (by a Java script loaded into the browser) to the other computer 403. Thus, caching would continue even when one of the two computers 403 are down.

[0053] The switch 404 may be, for example, a full duplex fast ethernet switch. A full duplex fast ethernet switch 404 can support data flowing in both directions at the same time (for example, between the caching server 402 and the head-end modems 406). The connections between the caching server 402 and the switch 404 may be made, for example, using 100 BaseT Ethernet.

[0054] The head-end modem 406 modulates analog carrier signals using the digital data received from the switch 404 and sends the modulated analog signals to the

multiplexer 407. The multiplexer 407 sends the modulated analog signals, along with TV signals received from the analog HE equipment, downstream to a node 122 of the distribution network.

[0055] Conversely, the multiplexer 407 receives an upstream modulated analog signal from the node 122 and sends the upstream signal to the modem 406. The modem 406 demodulates the modulated analog signals received from the multiplexer 407 to retrieve digital data that is then communicated to the switch 404.

[0056] There is need for typically over a hundred such head-end modems 406, one for each of the over a hundred nodes 122 typically supported by the modified head-end 120. Such a head-end modem 406 may be implemented, for example, with the LANcity head-end modem from the LANcity division of Bay Networks. The LANcity division is located in Andover, Massachusetts. Alternatively, communication with the end-user system 124 may be asymmetric in that the return path from the end-user system 124 may be via the public switched telephone network (PSTN) or some other communication channel.

[0057] The router 408 connects to the switch 404 and to an RDC 118 or a regional network 119 (which in turn connects to an RDC 118). The router 408 may be implemented, for example, using the 7505 router from Cisco Systems, and the connection between the router 408 and the fast switch 404 may be implemented, for example, using 100 BaseT Ethernet.

[0058] The terminal server (TS) 410 is connected to the caching server 402, the switch 404, the router 408, and the PSTN. The terminal server 410 provides, via the PSTN, an alternative backup communication and control channel between the modified head-end 120 and the RDC 118 or the NOC 126.

[0059] The monitor device 412 is a "synthetic load" saddled onto the digital network 180 via the router 408. The monitor 412 monitors the analog cable television distribution system via analog head-end equipment 414. The analog head-end equipment 414 typically receives local television (TV) signals via a terrestrial microwave dish or a satellite dish. These TV signals are fed into the multiplexers 407 and sent, along with the modulated analog signals from the cable modems 406, to nodes 122 of the distribution network. By communicating with the monitor 412, the NOC 126 of the digital network 180 is able to access the analog network management gear by "remote control."

[0060] Figure 5 is a diagram of a regional computer 304 within the RDC 118 in a preferred embodiment of this invention. The regional computer 304 includes hardware devices 502 and software devices in a memory module 504 connected by a bus system 506.

[0061] The hardware devices 502 include a central processing unit (CPU) 508, for example, an Intel 80x86, Motorola PowerPC, or Sun SPARC processor, communicating with various input/output (I/O) devices, such as a switch I/O 510 that connects to the high-speed switch 310, a disk I/O 512 that connects to the regional array controller 305, and a terminal server (TS) I/O 514 that connects to the terminal server 308. The CPU 508 and the various I/O devices each connect to the bus system 506 and communicate thereby.

[0062] The software devices in the memory module 504 include an operating system (OS) 516, for example, Windows NT or a flavor of UNIX, communicating with a regional distributed database management system (DDBMS) module 518, a regional network management system (NMS) agent 520, and various other software devices, such as a regional nameserver 522, a regional web server 524, a regional mail server 526, a regional news server 528, a regional subscription server 530, and a regional public key server 532.

[0063] The regional DDBMS software 518 handles back-end database functions, such as queries and transactions, for databases stored in the regional disk array 306. The regional DDBMS software 518 also handles front-end database functions, such as replication of certain data and multimedia content amongst the plurality of RDCs 118. In handling the front-end functions, the regional DDBMS software 518 communicates with the regional DDBMS software 518 in the other RDCs 118 and with the central DDBMS software 818 in the NOC 126. The regional DDBMS software 518 may be implemented, for example, using software from Oracle Corporation in Redwood Shores, California.

[0064] The regional NMS agent 520 monitors and proactively manages the part of the network under its regional data center (RDC) 118 and communicates the status of the region to a central NMS station 820 in the network operations center (NOC) 126. This hierarchical management of the network saves valuable bandwidth resources between the RDCs 118 and the NOC 126 and allows regional network faults to be more quickly repaired or circumvented. The regional NMS agent 520 may be implemented, for example, using NetExpert software from Objective Systems Integrators in Folsom, California.

[0065] The various other software devices perform various additional functions and services. For example, the regional nameserver 522 receives requests for IP addresses associated with domain names. For example, if the particular domain name is contained in the database of domain names stored at the regional server 302, then the regional nameserver 522 will return the associated IP address back to the end-user system 124 which made the request. The database of domain names (and corresponding IP addresses) is updated via replication from the central server 703 and amongst the regional servers 302.

[0066] The regional web (http) server 524 serves multimedia content from the regional server 302 to end-user systems 124. The multimedia content is served in the

form of html, vrml, image, audio, and video files, or may be in other forms. These files may be updated via replication from the central server 703 and amongst the regional servers 302. The regional web server 524 may be, for example, based on the Netscape Enterprise Server from Netscape Communications in Mountain View, California.

[0067] The regional web server 524 may also multicast select multimedia content, such as audio or video from live events, to select groups of the end-user systems 124. The multicasting may be performed using multicast IP which utilizes the user datagram protocol (UDP) to send IP packets selectively to multiple nodes in a logical group. Only one copy of the multimedia content being multicast will pass over any network link, allowing more efficient use of the available bandwidth between the RDCs 118 and the end-user systems 124.

[0068] The regional web server 524 may also serve requests originating from the public Internet 170. For example, a personal web page may be uploaded from the end-user system 124 to the RDC 118 and stored in a directory in the regional disk array 306. By configuring the regional web server 524, such a page may be made available to the Internet 170.

[0069] Figure 6 is a diagram of a caching computer 403 within the modified head-end 120 in a preferred embodiment of this invention. The caching computer 403 includes hardware devices 602 and software devices in a memory module 604 connected by a bus system 606.

[0070] The hardware devices 602 include a central processing unit (CPU) 608, for example, an Intel 80x86, Motorola PowerPC, or Sun SPARC processor, communicating with various input/output (I/O) devices, such as: (1) an inter-server I/O 610 that connects to another caching computer 403, (2) a switch I/O 612 that connects to the switch 404, (3) a terminal server (TS) I/O 614 that connects to the terminal server 410 in the modified head-end 120, (4) a cache storage device 616; and (5) a log storage device 618. The CPU

608 and the various I/O devices each connect to the bus system 606 and communicate thereby.

[0071] The software devices in the memory module 604 include an operating system 620, for example, Windows NT or a flavor of UNIX, communicating with a proxy server 621 which comprises a caching module 622 and a logging module 624. The proxy server 621 receives requests from end-user systems 124 for multimedia content. The multimedia content requested is in the form of html, vrm1, image, audio, and video files, or may be in other forms.

[0072] If the requested file is contained in the cache storage 616, then the proxy server 621 sends the file from the cache storage 616 to the requesting end-user system 124. The caching module 622 stores recently-served files in the cache storage 616. Files in the cache storage 616 are typically stored using a least-recently used (LRU) policy. LRU policy caches are well known in the pertinent art.

[0073] If the requested file is not contained in the cache storage 616, then the proxy server 621 sends out a request for the file via the router 408. When the requested file is received back at the proxy server 621, then the proxy server 621 forwards the file to the end-user system 124.

[0074] The preceding discussion describes a single level of proxy. Multiple levels of proxy are also possible. The second level of proxy would be, for example, at the RDC 118 level. The operation of such a system with two levels of proxy is illustrated and described below in conjunction with Fig. 11.

[0075] The logging module 624 stores transaction information in an access log file and an error log file stored in the log storage 618. The access log file includes information such as the hostname or IP address of the requester, the file requested, and

the time of the request. The error log file contains a record of problems encountered by the proxy server 621.

[0076] Figure 7 is a diagram of a network operations center (NOC) 126 in a preferred embodiment of this invention. The NOC 126 includes a local area network (LAN) 702 connecting together a central server 703 and a terminal server 710. The LAN 702 also connects to the router 116 between the backbone 102 and the RDC 118 and to the back office system 128.

[0077] The central server 703 may be implemented as a high-availability server. An example of such a high-availability central server 703 is shown in Figure 7, including two central computers 704 connected by array controllers 706 to a central disk array 708.

[0078] The terminal server 710 connects to the public switched telephone network (PSTN) and provides an alternate backup means by which to communicate from the NOC 126 to the RDCs 118 and the modified head-ends 120.

[0079] Figure 8 is a diagram of a central computer 704 within a network operations center 126 in a preferred embodiment of this invention. The central computer 704 includes hardware devices 802 and software devices in a memory module 804 connected by a bus system 806.

[0080] The hardware devices 802 include a central processing unit (CPU) 808, for example, an Intel 80x86, Motorola PowerPC, or Sun SPARC processor, communicating with various input/output (I/O) devices, such as a network I/O 810 that connects to the LAN 702 and a disk I/O 812 that connects to the array controller 706. The CPU 808 and the various I/O devices each connect to the bus system 806 and communicate thereby.

[0081] The software devices in the memory module 804 include an operating system (OS) 816, for example, Windows NT or a flavor of UNIX, communicating with a central distributed database management system (DDBMS) module 818, a central

network management system (NMS) station 820, and various other software devices, including a central nameserver 822, a central web server 824, a central mail server 826, a central news server 828, and a central public key server 830.

[0082] The central DDBMS software 818 handles back-end database functions for databases stored in the central disk array 708 and front-end database functions, such as replication of certain data and multimedia content between the NOC 126 and the RDCs 118. In handling the front-end functions, the central DDBMS software 818 communicates with the regional DDBMS software 518. The central DDBMS software 818 may be implemented, for example, using software from Oracle Corporation.

[0083] The central NMS station 820 communicates with and coordinates the regional NMS agents 518. The central NMS station 820 provides a "mission control" station for managing the private network 180. The central NMS station 820 may be implemented, for example, using NetExpert software from Objective Systems Integrators.

[0084] The various other software devices perform various additional functions and services. For example, the central nameserver 822 communicates with the regional nameservers to update the database of domain names stored at the RDCs 118.

[0085] Figure 9 is a diagram of a back office system (BOS) 128 in a preferred embodiment of this invention. The BOS 128 includes a local area network (LAN) 902 connecting together a back office server 903 and a terminal server 910. The LAN 902 also connects to the router 116 between the backbone 102 and the RDC 118 and to the NOC 126.

[0086] The back office server 903 may be implemented as a high-availability server. An example of such a high-availability back office server 903 is shown in Figure 9, including two back office computers 904 connected by array controllers 906 to a back office disk array 908.

[0087] The terminal server 910 connects to the public switched telephone network (PSTN) and provides an alternate backup means by which to communicate from the BOS 128 to the RDCs 118 and the modified head-ends 120.

[0088] Figure 10 is a diagram of a back office computer 904 within a back office system (BOS) 128 in a preferred embodiment of this invention. The back office computer 904 includes hardware devices 1002 and software devices in a memory module 1004 connected by a bus system 1006.

[0089] The hardware devices 1002 include a central processing unit (CPU) 808, for example, an Intel 80x86, Motorola PowerPC, or Sun SPARC processor, communicating with various input/output (I/O) devices, such as: (1) a network I/O 1010 that connects to the BOS LAN 902 and (2) an office disk I/O 1012 that connects to the array controller 906. The CPU 1008 and the various I/O devices each connect to the bus system 1006 and communicate thereby.

[0090] The software devices in the memory module 1004 include an operating system (OS) 1016, for example, Windows NT or a flavor of UNIX, communicating with a usage data analyzer 1018 and various other software devices, such as an office subscription server 1020.

[0091] The usage data analyzer 1018 communicates with the logging modules 624 in the modified head-ends 120. The usage data analyzer 1018 statistically analyzes the data in the access and error logs kept by the logging modules 624 in the log storages 618. Statistics analyzed include, but go well beyond, how many times a web page (an html file) was "hit" (accessed), when those hits occurred, and from what domains those hits came. Although in this embodiment the usage data analyzer 1018 is implemented in the BOS 128, it may also be implemented in the NOC 126.

[0092] The various other software devices perform various additional functions and services. For example, the office subscription server 1022 communicates with and updates the regional subscription servers 530 which keep track of services subscribed to by the end-user systems 124. Although implemented in the BOS 128, the office subscription server 1022 may also be implemented in the NOC 126.

[0093] Figure 11 is a flow diagram of a preferred method for providing data requested by a user to their system 124. The flow diagram illustrates the operation of a system with two levels of caching (a first level at the modified head-end 120 level and a second level at the RDC 118 level).

[0094] The process in Fig. 11 begins when an end-user system 124 requests 1102 content from a remote LAN source 114. This remote LAN source 114 may be, for example, the CNN WWW server, and the content may be a multimedia Web page from the CNN Web site. The following discussion will be in the context of multimedia content from CNN, but it applies to any data transfer across the Internet into a private network.

[0095] The caching server 402 at the "nearest" (i.e. most closely coupled) modified head-end 120 receives the request and determines 1104 whether or not the content requested is stored in its cache storage 616. If the content is stored in the cache 616, then the caching server 402 sends 1106 the content to the requesting end-user system 124. This first level of caching at the head-ends 120 more efficiently fulfills multiple requests for the same content by systems 124 served by the same head-end 120 because the often slow and unreliable Internet is bypassed for all but the first request from the locality served by the head-end 120.

[0096] Otherwise, the caching server 402 forwards the request to the regional server 302 at the "nearest" (i.e., most directly connected) regional data center 118. The regional server 302 determines 1108 whether the content is stored in its disk array 306. If the content is stored in the disk array 306, then the regional server 302 sends 1110 the

content to the caching server 402 at the modified head-end 120 nearest to the end-user system 124. That nearest caching server 402 then stores 1112 the content in its cache 616, and sends 1106 the content to the requesting end-user 124. This second level of caching at the RDCs 118 more efficiently fulfills multiple requests for the same content by systems 124 served by the same RDC 118 because the often slow and unreliable Internet is bypassed for all but the first request from the region served by the RDC 118.

[0097] Otherwise, if the content is not stored in the disk array 306, then the regional server 302 determines 1114 whether the backbone 102 or a RDC 118 has a direct connection via a router 130 to the remote LAN source 114. If such a direct connection exists, then the regional server 302 retrieves 1116 via the direct connection the content from the remote source 114 and stores 1118 the content in its disk array 306. The regional server 302 may then send 1110 the content to the caching server 402 nearest the requesting end-user system 124. The caching server 402 then stores 1112 the content in its cache storage 616 and sends 1106 the content to the requesting end-user system 124. This direct retrieval of the content via the router 130 more efficiently fulfills requests for content because the often unreliable and slow Internet is always bypassed.

[0098] Otherwise, if a direct connection to the remote LAN source 114 does not exist, then the regional server 302 retrieves 1122 the content from the remote source 114 via the backbone 102, the NAPs 106, and the Internet 170. The regional server 302 may then send 1110 the content to the caching server 402 nearest the requesting end-user system 124. The caching server 402 then stores 1112 the content in its cache storage 616 and sends 1106 the content to the requesting end-user system 124.

[0099] Figure 12 is a flow diagram of a preferred method 1200 of replicating data from a content provider. Replication 1206 is used to efficiently and rapidly disseminate select content across the private network 180 to substantially decrease the latency experienced by the users of the end-users systems 124.

[0100] The process 1200 in Fig. 12 begins when a content provider creates 1202 new or updated content to provide to the end-user systems 124 of the private network 180. The content may be located on a LAN 114 of the content provider. For example, the content provider may be CNN and the content a headline story including text, an image, and video footage on the verdict in the O.J. Simpson trial. Again, the following discussion will be in the context of multimedia content from CNN, but it applies to any data transfer across the Internet to a private network.

[0101] The content is then retrieved 1204 from the content provider to a regional server 302. The retrieval 1204 may occur, for example, via the Internet 170 or a more direct connection (such as through a router 130).

[0102] Next, the content is replicated 1206 from the regional server 302 to other regional servers 302 in the private network 180. The replication is accomplished by the regional DDBMS software 518 in the regional computers 304. The content may be fully or partially replicated amongst the regional servers 302. In full replication, a full copy of the content would be kept at every regional server 302. In partial replication, either the copies replicated are not full (i.e. only a partial fragment of the full copy is replicated), or the copies are not distributed to every regional server 302. In our example, the headline story might be broken down into a text fragment, an image fragment, and a video fragment, and perhaps only the text and image fragments would be replicated amongst all the regional servers 302.

[0103] After replication 1206, the content is served 1208 to fulfill requests from the end-user systems 124, for example, by the process 1100 shown in Fig. 11. In this way, replication 1206 may be combined with caching to decrease the latency experienced by end-users of the network architecture 100.

[0104] Figure 13 is a flow diagram of a preferred method 1300 of multicasting content that is customized to region or locality. Multicasting involves one-to-many

broadcasting. IP multicasting permits one or a few sources to broadcast data to multiple receivers in a logical group.

[0105] Referring back to Fig. 1, the hierarchical nature of the private network 180 allows for multicasting in the network 180 to be customized by region (e.g., area covered by an RDC 118) or locality (e.g., area covered by a modified head-end 120) in an organized and efficient manner. For example, regional or local weather information may be efficiently multicast in this manner. End-user systems 124 in different regions or localities may "tune into" the same IP multicast address and obtain data which is customized to a particular region or locality.

[0106] The process 1300 in Fig. 13 begins by assigning 1302 the content to be multicast to an IP multicast destination address. Under currently used protocols, such addresses are generally "class D" IP addresses, i.e. their first 4 bits are set to 1110.

[0107] Next, the content is customized 1302 into a version to suit a region or locality. For example, if the content was today's weather forecast, the forecast may be customized for the region of the San Francisco Bay Area or for the locality of the city of Palo Alto.

[0108] The customized content is multicast 1304 from a server in each region or locality to end-user systems 124 within the region or locality. For example, the San Francisco Bay Area weather forecast may be multicast by the RDC 118 serving the Bay Area to systems 124 in the Bay Area that are "tuned into" the multicast, or the Palo Alto weather forecast may be multicast by a modified head-end 120 serving part of Palo Alto to systems 124 in Palo Alto that are "tuned into" the multicast.

[0109] The above description is included to illustrate the operation of the preferred embodiments and is not meant to limit the scope of the invention. The scope of the invention is to be limited only by the following claims. From the above discussion,

many variations will be apparent to one skilled in the art that would yet be encompasses by the spirit and scope of the invention. For example, an optoelectronic node 122 in the HFC distribution system may be replaced by a router that connects to an ethernet hub of a LAN that covers an apartment building (multiple dwelling unit). As another example, the distribution infrastructure between the modified head-ends 120 and the end-user systems 124 may be implemented via xDSL (Asymmetrical Digital Subscriber Line, High bit-rate Digital Subscriber Line, or Symmetric Digital Subscriber Line) rather than a HFC distribution system. Furthermore, the connections and couplings described in the above specification need not be direct; rather, the connections and couplings may occur through various intermediate devices.